ELSEVIER

Ecological Economics 38 (2001) 275–291

ECOLOGICAL ECONOMICS

www.elsevier.com/locate/ecolecon

ANALYSIS

Resource use and technological progress in agriculture: a dynamic general equilibrium analysis

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Received 5 September 2000; received in revised form 29 January 2001; accepted 30 January 2001

Abstract

We analyze the global effects of economic and population growth and the impact of a slowdown in agricultural total factor productivity (TFP) on agriculture and forest resources using a dynamic multi-region computable general equilibrium model with land use and cover detail. Given the current consensus about the growth of the world economy, our results suggest that food security will not be threatened and agricultural activities will not encroach on forest resources over the next decade. A slowdown in agricultural TFP growth might lead to higher crop prices in all regions, with South East Asia facing the steepest increases. A slowdown in agricultural TFP growth also might be accompanied by higher conversion rates of forestland to farmland as well as by greater environmental or ecological damages on the remaining forestland. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Agricultural TFP growth; Population growth; Food security; Forestland

1. Introduction

The world's rate of population growth is slowing, but total population is still increasing at about 80 million per year, and is expected to reach 10 billion by the middle of the 21st century (World Bank, 1999). Most of this growth will take place in developing countries, particularly in Asia and Africa. These projected increases in population, along with growth in per-capita incomes and associated changes in demand for agricultural commodities, are expected to increase pressures on natural resources both through the expansion of land under cultivation and through more intense use of resources already employed in agricultural production. In support of these expectations, a recent study by Evenson et al. (1999) estimates that without the development of high yielding varieties of crops, prices for developing country consumers would likely be much higher than they are today. Technological ad-

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PII: S0921-8009(01)00165-3

vances in the cultivation of rice, for example, have reduced costly food imports by 8% and have eliminated the need to convert millions of hectares of forestland to agricultural uses as would have been required had yields remained at 1960 levels. This evidence highlights the central role of agricultural research in ensuring sustainable rural development and food security in high growth developing countries, and reducing the strain on forest ecosystems.

Research on technical advances in agriculture is abundant. Norton and Davis (1981), Alston (1993) provide exhaustive surveys of the literature on gains from agricultural research. Very few of the reviewed studies, however, examine the impacts of agricultural research in an international context and the effects of technological spillovers across regions. A more recent paper by Frisvold (1997) has filled in this gap in the literature by analyzing the open economy aspects of agricultural research in a multi-region general equilibrium context with the Global Trade Analysis Project (GTAP) model (Hertel, 1997). The paper nicely illustrates how international spillovers are important aspects of agricultural research. It also extends the analysis of spillovers in a single commodity, single stage of production setting (Edwards and Freebairn, 1984) by considering the full multi-region, general equilibrium implications of such spillovers. The methodology adopted by Frisvold overcomes two of the limiting assumptions of the single-commodity, partial equilibrium models used by most returns-to-research studies, namely, that prices and production of all other commodities are fixed, and that research results from one region do not affect the productivity in others. The methodology does not, however, account for the dynamic effects of economic and population growth or calculate land-use changes between the agricultural sector and the rest of the economy.

The methodology used by Frisvold was extended by Darwin et al. (1995, 1996) in the Future Agricultural Resources Model (FARM) to include the competition for land among agriculture, forestry, and all other sectors in the economy. The methodology was also extended by Ianchovichina and McDougall (2000) to include a dynamic theory of asset ownership and investment. These two extensions are combined in a dynamic version of FARM (D-FARM), which we use to examine how agricultural total factor productivity (TFP) interacts with forestland use and timber harvest rates.

Our results support the findings by Evenson et al., 1999) that a slowdown in agricultural TFP will raise world prices and lower world production of agricultural commodities while expanding farmland usage. This expansion in demand for farmland leads to permanent conversion of forestland into farmland and increases the environmental threat from deforestation. The loss in productivity in agriculture affects welfare in all regions negatively, with the bulk of the problems faced by regions in which agriculture accounts for a higher share of the gross domestic product.

The paper is structured as follows. Section 2 describes the modeling framework and solution procedure, and discusses the data and parameters. Section 3 discusses the design of and the results from the baseline simulation. Section 4 focuses on the effects of a slowdown in agricultural TFP with spillover effects. We summarize the major findings of the study in Section 5.

2. Methodology

This research uses D-FARM to estimate how TFP interacts with forestland use and timber harvest rates during the period from 2000 to 2007. This section briefly describes D-FARM's structure, outlines the solution procedure, and discusses the data and parameters.

2.1. The modeling framework

D-FARM, an extension of GTAP (Hertel, 1997), is a global, multi-commodity, applied general equilibrium (AGE) model with 12 regions and 18 commodities, 11 of which are agriculture-related products (Table 1). D-FARM incorporates global production, consumption, trade and policy distortions and offers a systematic way for determining the likely pattern of changes in factor and commodity prices, and production around

Table 1
Regional, sectoral, factor and commodity aggregation for D-FARM

A. Regional aggregation	*D. Commodity aggregations*
1. ANZ — Australia and New Zealand	1. PDR — Paddy rice
2. CAN — Canada	2. WHT — Wheat
3. USA — United States and Canada	3. GRO — Other grains
4. JPN — Japan	4. V-F — Vegetables, fruits, nuts
5. OEA — Other East Asia: Korea, China Hong Kong, Taiwan	5. OSD — Oilseeds
6. SEA — South East Asia: Indonesia, Malaysia, Philippines, Thailand, Singapore	6. C-B — Sugar cane and sugar beet
7. EU — European Union	7. PFB — Plant-based fibers
8. FSU — Former Soviet Union	8. OCR — Other crops
9. OEU — Other Europe	9. LIV — Livestock: wool, other livestock products
10. LAM — Latin America	10. FOR — Forestry
11. AFR — Africa	11. COG — Coal, oil, and gas
12. OAS — Other Asia	12. MIN — Other minerals
	13. FMM — Fish, meat, and milk: fishing, meat products, milk products
B. Sectoral aggregation	14. OPF — other processed foods: processed rice, other food products, beverages and tobacco
1. CRP — Crops (six sectors)	15. TCF — Textiles, clothing, and footwear: textiles, wearing apparel
2. LIV — Livestock (six sectors)	16. NMM — Other nonmetalic manufactures: lumber and wood products, pulp, paper and printed products petroleum and coal products chemicals, rubber, and plastic nonmetalic mineral products
3. FOR — Forestry (six sectors)	17. OMN — Other manufactures: primary iron and steel, fabricated nonferrous metals, transport industries, other machinery and equipment other manufacturing
4. COG — Coal, oil and gas	18. SRV — Services: electricity, gas, water, construction, trade and transport, other services
5. MIN — Other minerals	19. CGDS — Capital goods formation
6. FMM — Fish, meat, and milk	
7. OPF — Other processed food	
8. TCF — Textiles, clothing, and footwear	
9. NMM — Other nonmetallic manufactures	
10. OMN — Other manufactures	
11. SRV — Services	
12. CGDS — Capital goods formation	
C. Endowments	
1–6 Six land classes	
7. Water	
8. Skilled Labor	
9. Unskilled Labor	
10. Capital	
11. Natural Resource Factor	

the world in response to changes in farm productivity while taking into account the complex linkages among sectors and regions over time. In each region, a representative, regional household maximizes utility so that regional income is allocated in fixed value shares across private consumption, government services, and saving. Private household demands are represented via the constant difference of elasticities (CDE) implicit expenditure function. The CDE structure is less restrictive than other functional forms in that the elasticities of substitution between pairs of commodities can differ and income elasticities are not restricted to equal one (Tables 2 and 3).

Producers maximize profits and operate in perfectly competitive markets. A commodity is produced from a composite input obtained by combining a composite primary factor and a composite intermediary product using a Leontief technology. The composite primary factor input is a constant elasticity of substitution (CES) composite of land, skilled and unskilled labor, physical capital, and natural resource inputs. The composite intermediate input consists of 18 com-

Table 2
Own-price elasticities of demand in the D-FARM at initial equilibrium, by region[a]

	ANZ	CAN	USA	JPN	OEA	SEA	EU	FSU	OEU	OAS	LAM	AFR
PDR	−0.076	−0.071	−0.116	−0.070	−0.072	−0.059	−0.075	−0.058	−0.010	−0.046	−0.067	−0.116
WHT	−0.082	−0.071	−0.116	−0.070	−0.069	−0.074	−0.113	−0.058	−0.078	−0.048	−0.082	−0.062
GRO	−0.080	−0.071	−0.116	−0.070	−0.067	−0.071	−0.105	−0.058	−0.067	−0.057	−0.053	−0.066
V-F	−0.110	−0.066	−0.070	−0.268	−0.222	−0.172	−0.190	−0.167	−0.179	−0.163	−0.190	−0.141
OSD	−0.069	−0.062	−0.067	−0.264	−0.226	−0.174	−0.151	−0.167	−0.182	−0.135	−0.202	−0.123
C-B	−0.237	−0.061	−0.067	−0.264	−0.283	−0.173	−0.167	−0.167	−0.188	−0.135	−0.172	−0.115
PFB	−0.159	−0.061	−0.067	−0.264	−0.214	−0.174	−0.147	−0.167	−0.206	−0.135	−0.186	−0.136
OCR	−0.161	−0.062	−0.069	−0.264	−0.202	−0.151	−0.189	−0.167	−0.192	−0.148	−0.188	−0.137
LIV	−0.165	−0.095	−0.066	−0.598	−0.217	−0.185	−0.173	−0.085	−0.113	−0.129	−0.147	−0.130
FOR	−0.782	−0.785	−0.885	−1.00	−0.407	−0.520	−0.880	−0.398	−0.616	−0.316	−0.501	−0.295
COG	−0.659	−0.710	−0.776	−0.898	−0.280	−0.435	−0.728	−0.310	−0.364	−0.320	−0.339	−0.351
MIN	−0.782	−0.787	−0.885	−1.00	−0.784	−0.498	−0.870	−0.398	−0.532	−0.313	−0.400	−0.277
FMM	−0.104	−0.094	−0.079	−0.516	−0.254	−0.163	−0.174	−0.095	−0.124	−0.168	−0.146	−0.180
OPF	−0.348	−0.246	−0.317	−0.401	−0.227	−0.165	−0.354	−0.185	−0.317	−0.179	−0.215	−0.164
TCF	−0.590	−0.590	−0.668	−0.756	−0.371	−0.361	−0.634	−0.266	−0.497	−0.213	−0.343	−0.209
NMM	−0.728	−0.725	−0.834	−0.939	−0.460	−0.444	−0.676	−0.369	−0.691	−0.353	−0.443	−0.360
OMN	−0.669	−0.680	−0.782	−0.893	−0.467	−0.448	−0.755	−0.311	−0.661	−0.328	−0.407	−0.297
SRV	−0.155	−0.175	−0.174	−0.229	−0.278	−0.204	−0.326	−0.102	−0.284	−0.188	−0.206	−0.173

[a] Source: Version 4 GTAP database (Chap. 19: www.agecon.purdue.edu/gtap/database).

Table 3
Income elasticities for private consumption in the D-FARM, by region[a]

	ANZ	CAN	USA	JPN	OEA	SEA	EU	FSU	OEU	OAS	LAM	AFR
PDR	0.131	0.130	0.168	0.162	0.435	0.174	0.147	0.187	0.206	0.313	0.195	0.686
WHT	0.137	0.130	0.168	0.162	0.435	0.370	0.185	0.187	0.205	0.301	0.267	0.353
GRO	0.135	0.130	0.168	0.162	0.413	0.365	0.177	0.187	0.200	0.311	0.183	0.384
V-F	0.194	0.128	0.141	0.355	0.734	0.635	0.291	0.543	0.499	0.593	0.527	0.642
OSD	0.134	0.128	0.141	0.355	0.641	0.634	0.236	0.543	0.445	0.732	0.504	0.641
C-B	0.380	0.128	0.141	0.355	0.527	0.661	0.276	0.543	0.284	0.723	0.580	0.633
PFB	0.270	0.128	0.141	0.355	0.420	0.662	0.226	0.543	0.347	0.734	0.529	0.650
OCR	0.273	0.128	0.141	0.355	0.815	0.479	0.291	0.543	0.415	0.661	0.537	0.637
LIV	0.262	0.153	0.118	0.689	1.054	0.650	0.253	0.281	0.357	0.637	0.447	0.624
FOR	1.121	1.114	1.118	1.089	1.321	1.167	1.129	1.151	1.342	1.524	1.221	1.514
COG	0.992	0.998	1.004	0.992	1.102	1.022	0.994	0.920	1.147	1.013	1.030	0.915
MIN	1.121	1.114	1.118	1.089	1.183	1.183	1.121	1.151	1.385	1.343	1.232	1.535
FMM	0.155	0.138	0.117	0.611	0.668	0.570	0.236	0.297	0.290	0.557	0.403	0.618
OPF	0.624	0.450	0.520	0.498	0.667	0.597	0.551	0.627	0.637	0.691	0.621	0.689
TCF	0.927	0.925	0.941	0.881	0.934	0.919	0.922	0.875	1.018	0.909	0.943	0.939
NMM	1.120	1.114	1.118	1.089	1.285	1.263	1.123	1.151	1.333	1.289	1.216	1.343
OMN	1.068	1.076	1.128	1.065	1.180	1.066	1.055	1.063	1.185	1.148	1.145	1.215
SRV	1.079	1.075	1.046	1.112	1.155	1.223	1.078	1.117	1.103	1.221	1.182	1.256

[a] Source: Version 4 GTAP database (Chap. 19: www.agecon.purdue.edu/gtap/database).

posite commodity inputs, which, in turn, are composed of domestic and imported versions of themselves. Each of the 18 composite commodity inputs is derived from nested CES cost functions — one for determining the amount to be imported from each region, and another for choosing the import–domestic mix in the composite intermediate product. The Allen partial elasticities of substitution for these CES functions are displayed in Table 4. The model captures how differences in relative rates of factor accumulation interact with differential sectoral factor intensities giving rise to the so-called 'Rybczynski' effects.[1] These type effects have been found to be important determinants of structural change (Krueger, 1977; Leamer, 1987; Martin and Warr, 1993).

Product differentiation between imports and domestic products, and imports by region of origin (the Armington assumption) allows for two-way trade in each product category, depending upon the ease of substitution between prod-

[1] Rybczynski showed that, at constant prices, an increase in one factor endowment will increase by a greater proportion the output of the good intensive in that factor and will reduce the output of the other good.

Table 4
Allen partial elasticities for primary factors (σ) and between domestic and imported commodities (ω)[a]

Sectors	σ	Commodities	ω
CRP 1 to 6	0.24	PDR	2.20
	0.24	WHT	2.20
	0.24	GRO	2.20
LIV 1 to 6	0.24	V-F	2.20
	0.24	OSD	2.20
	0.24	C-B	2.20
FOR 1 to 6	0.20	PFB	2.20
	0.20	OCR	2.20
	0.20	LIV	2.78
		FOR	2.80
COG	0.20	COG	2.80
MIN	0.20	MIN	2.80
FMM	0.29	FMM	2.29
OPF	1.12	OPF	2.45
TCF	1.26	TCF	3.32
NMM	1.26	NMM	2.05
OMN	1.26	OMN	3.33
SRV	1.40	SRV	1.94

[a] Source: Version 4 GTAP Database (Chap. 19: www.agecon.purdue.edu/gtap/database).

ucts from different regions. All factor inputs are fully employed and immobile across regions, and with the exception of land and the natural resource input, are perfectly mobile across sectors. The returns to these factors, except in the case of capital,[2] accrue to the households in the regions in which they are employed. All factor inputs except land are homogeneous.

Land in D-FARM is divided into six land classes based on the length of the growing season — the longest continuous period of time in a year that soil temperature and moisture conditions support plant growth. Land classes 1 and 2 have growing seasons of 100 days or less. Land class 1 occurs where cold temperatures limit growing seasons — mainly polar and alpine areas. Canada and the former Soviet Union contain 79.3% of the world's endowment of land class 1. Growing seasons on land class 2, which represent mainly semi-desert and desert areas, are limited by low precipitation levels. Land class 3 has growing seasons of 101–165 days and is 13% of all land. About half of the land class 3 endowment is located in Canada and the Former Soviet Union. Land class 4 represents only 10.2% of land and has growing seasons ranging from 166 to 250 days. About 29% of land class 4 is located in Africa, and another 27.6% in the United States and Europe. Land class 5, which has growing seasons of 251–300 days, is only 7.7% of the world land area. Most of it (78.8%) is located in Africa, Latin America, and Asia. Land class 6, located mainly in the tropical areas of Africa, Asia and Latin America, accounts for 20% of all land and has year-round growing seasons.

Each land class in D-FARM supplies services to 26 commodity producing sectors according to constant-elasticity-of-transformation (CET) functions (Table 1). Eight of these sectors are manufacturing and services. The remaining 18 are crop, livestock, and forestry sectors specific to the land class. For example, land class 1 supplies services to crops sector 1, livestock sector 1, forestry sector 1, and to the eight manufacturing and services sectors. This way there are six land-class-specific crops, livestock, and forestry sectors. Each manufacturing and services sector uses all land classes, while each crop, livestock and forestry sector uses only one land type. The CET functions, which restrict land's mobility among sectors, allow land to shift among economic sectors without losing sight of land's inherent productivity differences.

The crop sectors are multi-output sectors producing their own mix of eight crop commodities (Table 1). The mix is determined by CET functions with Allen partial elasticities less than zero. Regional production of the eight crop varieties is the sum of production of the six crop sectors. Each livestock and forestry sector produces only one aggregate commodity — livestock and forestry, respectively. Regional livestock and forestry outputs are also obtained by summing production across the six livestock and forestry sectors associated with the different land classes, respectively. In all other sectors, the final composite input equals output, and production is not land-class specific.

The investment theory, described in detail in Ianchovichina and McDougall (2000), allowed us to link economic activity over time while keeping track of endogenous regional capital stocks and financial wealth, international assets and liabilities, and international investment and income flows. Investment funds are used for the purchase of physical investment goods, which are then added to the existing stock of physical capital. Thus, financial assets represent claims to the ownership of physical capital. The theory respects the empirical regularity that regions tend to invest primarily in assets located in their domestic economy. A smaller portion of investment comes from abroad, and therefore, a share of the regional capital stocks is foreign-owned. While the physical capital stock is mobile across sectors, and not across regions, ownership shares of this capital are internationally mobile. With financial assets mobile across regions, national accounts reflect international income payments. Thus, the impact on the gross domestic and gross national products of policies that affect capital in a region may differ substantially. Investors, who respond to expected rates of return and act so as to eliminate errors in their expectations gradually over time,

[2] We describe the treatment of income from capital when we discuss the dynamic theory in D-FARM.

determine the pattern of investment in the model. Any differences in the risk-adjusted rates of return across regions that might exist in the short run are eliminated by a reallocation of capital from regions with lower rates of return to regions with higher rates of return in the long run.

2.2. The solution procedure

Time in D-FARM is a variable (not an index), subject to exogenous changes along with the usual policy, technology, and demographic variables. Shocks to the time variable define the change in time through the simulation, while shocks to other exogenous variables represent accompanying changes in external circumstances. In the presence of non-zero net investment or saving, the passage of time leads to changes in the stock of physical capital or wealth, and in the long run to equilibration of rates of return.[3]

D-FARM is implemented in GEMPACK (Harrison and Pearson, 1995) and is solved in a recursive fashion via non-linear methods. This solution method produces a sequence of results representing yearly changes in the endogenous variables. The solution for each period in the sequence maintains all equilibrium conditions embodied in the data and other restrictions imposed by the economic theory. Changes in consumer demands exhaust changes in regional spending, regional output determines income generated in the region, each region's total exports equal total imports of these goods into other regions (less shipping costs), global investment equals the sum of regional savings, and the sum of capital stock around the world equals total accumulated wealth.

The solution procedure is handled via Windows-based software, RunDynam, which makes it easy for the user to specify experiments, solve the model over the simulation time horizon, and explore the simulation results. RunDynam produces a sequence of solution files with results that represent percentage changes from previous period data both for a 'base' run and a 'policy' run. The software also produces a sequence of files with compounded results that represent percentage changes from the initial year, again both for the 'base' and 'policy' runs. RunDynam also computes the difference between the compounded results from the 'policy' and 'base' runs, and thus can isolate, for example, the impact of a slowdown in agricultural TFP.

2.3. The data

The economic data by region, sector, and commodity are from version 4E (with upgraded energy content) of the GTAP database (McDougall et al., 1998). Economic values of inputs and outputs were distributed to the land classes based on their respective shares in 1990 as derived by FARM's geographic information system (Darwin et al., 1995, 1996; Darwin, 1999). These GTAP data have been enriched with financial data required by the investment theory in D-FARM (Ianchovichina, 1998).

In order to capture the longer-term effects of agricultural productivity, we develop a baseline scenario that traces the growth of the world economy until 2007. This baseline utilizes estimates of annual growth rates for regional GDP, gross domestic investment (GDI), population, skilled labor, and unskilled labor (Tables 5–7). These estimates are part of the GTAP Version 4 database. They are based on projections collected from various sources and assembled together for the GTAP database at the Center for Global Trade Analysis, Purdue University (Walmsley et al., 2000). The GDP, GDI, population and labor projections were obtained from the World Bank, while skilled labor projections were obtained from two sources. For the less developed countries projections of the share of secondary and tertiary educated labor were obtained from Ahuja and Filmer (1995). For the developed countries these projections were obtained from CPB (1999).

The policy projections encompass the implementation of the Uruguay Round (UR), tariff reductions implemented during 2000 by the Chinese prior to World Trade Organization (WTO)

[3] Ianchovichina and McDougall (2000) present a comprehensive discussion of treating time as a variable in a dynamic model.

Table 5
Gross domestic product: annual growth rates (%)[a]

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
ANZ	3.8	3.2	2.8	3.1	2.4	2.8	3.2	3.4	3.4	3.4	3.4	3.4
CAN	2.3	1.5	3.8	2.9	2.1	2.5	2.6	2.8	2.6	2.7	2.9	2.7
USA	2.4	2.4	3.8	3.9	3.1	2.1	2.4	2.5	2.6	2.5	2.6	2.5
JPN	1.4	3.5	0.9	−2.9	−1.1	0.3	0.9	1.5	2.3	2.1	2.2	2.1
OEA	8.9	7.9	7.2	2.6	4.3	5.5	6.1	6.4	6.5	6.6	6.6	6.7
SEA	8.3	7.2	3.4	−7.2	−0.9	3.0	4.4	5.1	5.5	5.8	5.7	5.7
EU	2.3	1.7	2.5	2.8	2.0	2.7	2.6	2.7	2.7	2.6	2.6	2.5
FSU	−5.2	−4.3	1.2	−3.4	−5.5	0.6	2.4	4.0	4.8	5.2	5.2	5.2
OEU	3.4	2.5	2.4	2.6	2.3	2.7	3.0	3.0	3.1	3.1	3.2	3.2
OAS	5.0	5.3	4.9	2.5	1.9	3.2	3.9	4.2	4.4	4.4	4.4	4.4
LAM	1.3	3.5	5.1	1.9	−1.0	2.4	3.9	4.3	4.3	4.4	4.5	4.5
AFR	2.9	4.7	2.8	2.9	2.6	3.8	4.0	4.1	4.1	4.1	4.2	4.2

[a] Source: The Center for Global Trade Analysis and the World Bank.

Table 6
Target versus achieved annual gross domestic investment growth rates (%)[a]

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
ANZ	1.7[b]	5.0	1.2	3.1	2.6	2.7	4.2	4.7	4.6	4.5	4.5	4.5
	−1.3[c]	*4.2*	*2.2*	*4.6*	*3.7*	*2.8*	*4.0*	*4.4*	*4.5*	*4.4*	*4.4*	*4.4*
CAN	1.3	−2.4	17.0	5.6	4.4	3.5	3.4	3.2	2.8	3.0	3.3	3.0
	−1.7	*−3.0*	*18.0*	*7.2*	*5.6*	*3.7*	*3.2*	*2.9*	*2.7*	*2.8*	*3.1*	*2.8*
USA	5.4	5.7	7.1	6.6	4.2	2.0	2.8	1.6	1.6	1.9	1.7	1.6
	2.3	*5.0*	*8.1*	*8.2*	*5.4*	*2.2*	*2.6*	*1.3*	*1.6*	*1.7*	*1.6*	*1.4*
JPN	2.1	6.7	−4.8	−8.4	−4.2	0.3	1.0	2.9	2.1	1.8	2.1	2.1
	−0.9	*6.0*	*−4.0*	*−7.0*	*−3.1*	*0.4*	*0.8*	*2.5*	*2.1*	*1.7*	*1.9*	*1.9*
OEA	13.1	7.0	2.8	0.4	4.5	5.8	6.6	7.2	7.2	7.4	7.3	7.6
	9.8	*6.2*	*3.8*	*2.0*	*5.7*	*6.0*	*6.4*	*6.8*	*7.1*	*7.2*	*7.2*	*7.4*
SEA	13.6	10.3	−3.2	−21.2	−7.5	0.8	4.0	5.8	6.2	6.6	6.6	6.6
	10.2	*9.6*	*−2.3*	*−20.0*	*−6.4*	*0.9*	*3.8*	*5.5*	*6.1*	*6.4*	*6.4*	*6.4*
EU	4.2	−0.7	2.5	4.6	3.5	3.3	2.8	3.4	3.2	3.2	3.2	3.1
	1.2	*−1.4*	*3.4*	*6.2*	*4.6*	*3.5*	*2.6*	*3.0*	*3.1*	*3.0*	*3.1*	*3.0*
FSU	−5.0	−15.0	−5.0	−12.5	−9.5	2.0	4.0	5.0	6.0	7.0	7.0	7.0
	−7.8	*−15.6*	*−4.1*	*−11.2*	*−8.5*	*2.1*	*3.8*	*4.6*	*5.9*	*6.8*	*6.8*	*6.8*
OEU	9.3	7.2	4.2	6.6	3.2	4.5	4.6	4.7	4.8	4.9	4.9	4.9
	6.1	*6.4*	*5.1*	*8.2*	*4.4*	*4.7*	*4.4*	*4.4*	*4.7*	*4.7*	*4.7*	*4.8*
OAS	28.3	4.8	4.7	0.3	1.5	3.5	4.3	5.0	5.0	5.0	5.0	5.0
	24.5	*4.1*	*5.7*	*1.8*	*2.7*	*3.6*	*4.1*	*4.6*	*4.9*	*4.8*	*4.9*	*4.9*
LAM	3.9	4.3	10.4	3.9	−5.1	4.2	5.9	5.3	5.3	5.4	5.4	5.4
	0.9	*3.5*	*11.4*	*5.5*	*−4.0*	*4.3*	*5.7*	*4.9*	*5.2*	*5.2*	*5.3*	*5.2*
AFR	7.5	6.6	5.1	3.1	4.5	5.7	6.0	5.9	5.9	6.1	6.1	6.1
	4.4	*5.8*	*6.1*	*4.7*	*5.7*	*5.9*	*5.8*	*5.5*	*5.9*	*5.9*	*5.9*	*5.9*

[a] Source: Center for Global Trade Analysis and the World Bank.
[b] Target annual gross domestic growth rates.
[c] Annual gross domestic growth rates achieved with D-FARM.

accession, the implementation of China's accession to the WTO, the implementation of the Agreement on Textiles and Clothing, and finally shocks to tariff rates required to simulate a slow decrease in tariffs after the completion of the Uruguay Round. Post-UR tariff estimates, based on post-UR information from version 3 of the GTAP database and the GATT/WTO integrated database (IDB), were obtained from Francois and Strutt (1999). Subsequently, these estimates were updated to reflect the GTAP Version 4 database. Fan and Zheng (2000) supplied information on tariffs imposed by China on some commodities. Estimates on tariff rates offered by China for their accession to the WTO based on the August 1999 offer were obtained from Martin et al. (2000) of the World Bank. Yearly policy shocks for the period 1995–2007 were computed by Walmsley et al. (2000).

Most parameters in D-FARM are inherited from GTAP (Hertel, 1997) and are based on a review of the literature. These include the Allen partial elasticities for primary factors, imported intermediates (Table 4), and the price and income elasticities for private consumption (Tables 2 and 3). In Darwin et al. (1996) the CET functions for land services have Allen partial elasticities of $-$1.0. In this study we set these elasticities 50% lower to reflect that land movements are more restricted within the shorter time horizon of one year. Since there are few estimates of Allen partial elasticities of substitution for crop supplies, we have set the values of these elasticities to -1. This reduces the CET functions to Cobb–Douglas ones and means that the revenue shares for crops services and livestock services, for example, received by land owners and the revenue shares received for wheat, other grains, and non-grains by crop producers within a region are constant, but not equal, across all levels of revenue (Darwin et al., 1995). We set the parameters determining the speed of adjustment in the investment theory of the model as in Ianchovichina and McDougall (2000). Darwin et al. (1995) conducted a sensitivity analysis to test the importance of parameter specification to model results. They concluded that measures of total or sectoral world products are not very sensitive to changes in parameters. The signs of changes remained the same in all cases when these elasticities were changed by 50% in either direction.

3. Simulation design and baseline results

Our baseline simulation strategy is to rely on outside projections for the macroeconomics, and use D-FARM to determine sectoral and trade results by projecting the world economy between 1995 and 2007. The process of tailoring the model to outside macro forecasts involves a two-step procedure for calibrating a technical change scenario in order to achieve the GDP and GDI growth rates in Tables 5 and 6, respectively.

The first step covers the period between 1995 and 2000. It involves calibrating a regional factor-saving technological change parameter, *F*, which is used as an instrument to achieve a GDP target in each region, and a risk premium parameter, which is used to achieve the GDI targets and represents changes in investors' expectations about returns to capital in each region during the period of the Asian crisis and the subsequent financial turmoil in Latin America and the Former Soviet Union. A shock to *F* specifies a technological change specific to each region, uniform across industries within each region, applying to all factors other than physical capital, and uniform across the factors to which it applies. The final database from this first step of the calibration procedure serves as a starting point for the projections until 2007.

The second step of the calibration procedure covers the period between 2000 and 2007. It involves again calibrating the regional factor-saving technological change parameter *F*, and a parameter *B*, defining regional technological bias towards physical capital, which is used to achieve a regional GDI target. Average factor productivity growth rates for *F* in this period are shown in Table 7. Unlike *F*, parameter *B* does not represent an improvement or deterioration in technology, but merely a change in bias of technology towards the use of physical capital.

The realized annual GDP growth rates match the target annual GDP growth rates (Table 5). Table 6 shows target, and below them in *italics*, achieved annual GDI growth rates. A comparison of the numbers in this table indicates that the target GDI growth rates are in most cases very close to the achieved GDI growth rates. Total

Table 7
Macroeconomic scenario: annual growth rates for selected variables (%)

Region	Population[a]	Unskilled labor[a]	Skilled labor[a]	Average productivity growth: F[b]
ANZ	0.8	1.1	0.9	2.6
CAN	0.8	0.9	0.9	1.8
USA	0.9	1.0	1.0	1.5
JPN	0.2	−0.2	−0.6	0.8
OEA	0.7	0.5	3.3	5.4
SEA	1.4	1.4	6.4	5.7
EU	0.1	−0.2	0.0	2.0
FSU	0.3	0.7	1.0	4.5
OEU	0.2	0.1	0.3	2.1
OAS	1.6	2.4	5.1	1.7
LAM	1.4	1.3	5.5	4.0
AFR	2.4	2.6	3.3	1.7

[a] Source: Center for Global Trade Analysis and the World Bank.
[b] Source: calibration performed with D-FARM.

Table 8
Growth rates in public agricultural research expenditures and agricultural productivity[a]

	Public agricultural research expenditures			Average agric. productivity growth in baseline[c] (%)	Average agric. productivity growth in alternative case (%)
Region	1971	1991	Average growth: 1971–1991 (%)		
Developed regions	4320	6956	2.41	2.60[d]	1.90[d]
Other East Asia — China	457	1494	6.10	6.10	5.40
South East Asia	861	3502	7.27	6.40	5.70
Latin America	507	944	3.16	4.70	4.00
Africa	1158[b]	2068[b]	2.94	2.40	1.70

[a] Source: Table 3.12 in Alston et al., 1999). Numbers in columns 2 and 3 of this table are in millions of 1985 international dollars.
[b] This number is the sum of public agricultural expenditure in Sub-Saharan and North Africa (incl. West Asia).
[c] Numbers in this column equal those in the last column of Table 7 plus 0.7 percentage points.
[d] This is an estimate based on the results in the last column of Table 7 for Australia and New Zealand, Canada, US, Japan, and the European Union.

factor productivity is exogenous both in the baseline and policy simulations.[4] The calibration to the GDP and GDI targets in Table 4 produced growth rates in technology that we used both in the base and policy runs. Rates of growth in agricultural TFP were assumed to be slightly faster (0.7% per year) than for non-agriculture in all regions based on evidence from Bernard and Jones (1993).

Since the agricultural technical change scenario is an important determinant of the baseline results, we compare agricultural TFP growth rates with growth rates in public agricultural research expenditures over the past 20 years for selected regions in our model.[5] The growth rates in Table

[4] Total factor productivity parameters were treated as endogenous variables only for the purpose of calibrating to the GDP targets in Table 5.

[5] Data on public agricultural research expenditure for the other regions in our study were not available.

Table 9
World prices and production by commodity[a]

Commodity	Baseline average annual % change in		Average annual % change from baseline due to a slowdown in agricultural TFP in	
	Price	Output	Price	Output
1. PDR — Paddy rice	−1.2	4.2	0.91	−0.23
2. WHT — Wheat	−0.5	3.0	0.83	−0.13
3. GRO — Other grains	−0.9	2.7	0.89	−0.11
4. V-F — Vegetables, fruits, nuts	−0.9	3.1	0.82	−0.19
5. OSD — Oilseeds	−0.4	3.2	0.91	−0.16
6. C-B — Sugar cane and sugar beet	−0.1	3.4	0.89	−0.20
7. PFB — Plant-based fibers	−0.2	4.1	0.88	−0.18
8. OCR — Other crops	−1.0	2.9	0.88	−0.15
9. LIV — Livestock	−0.7	3.2	0.67	−0.14
10. FOR — Forestry	0.3	3.6	0.08	−0.08
11. COG — Coal, oil, and gas	6.1	3.3	−0.35	−0.03
12. MIN — Other minerals	1.0	3.6	−0.07	−0.03
13. FMM — Fish, meat, and milk	−0.3	2.3	0.28	−0.08
14. OPF — Other processed foods	−0.3	2.5	0.22	−0.09
15. TCF — Textiles, clothing, footwear	−0.2	3.2	0.05	−0.07
16. NMM — Other nonmetalic mnfc.	0.9	3.0	−0.06	−0.03
17. OMN — Other mnfc.	0.4	3.3	0.00	−0.01
18. SRV — Services	−0.1	3.0	0.00	−0.02

[a] Source: simulations with D-FARM.

8 provide only a rough estimate of historical growth rates of agricultural research expenditures because private expenditures might be sizable, especially in developed regions. The numbers in Tables 7 and 8 suggest that the average agricultural productivity growth rates assumed in the baseline are in line with the historical average growth in agricultural public expenditures. The only exception is Latin America, where our study assumes an agricultural TFP growth rate that is more than a percentage point higher than the historical growth rate for public agricultural research expenditures.

The results presented next are not predictions. Our main purpose is to show the ecological–economic information generated by the proposed framework given our assumptions. By examining these results, we obtain a better understanding of the interrelationships among economic and ecological variables.

The baseline results represent the effects of world population growth and economic growth based on our trade policy scenario and international capital movements. The baseline results suggest that, given the current consensus about the growth of the world economy represented by the macroeconomic assumptions in our study and our assumptions about agricultural technical change, food security problems are not likely to be exacerbated over the next decade. Prices of all farm and food commodities, for example, decline (Table 9).[6] Fig. 1 shows the time paths of yearly percentage changes in the world prices of rice, wheat, other grains, and vegetables. Average production growth rates for all major crops vary between 2.7 and 3.0% per annum and are higher than world population growth rates (Table 7). Thus the world is not expected to experience shortages of food supplies over the medium term, e.g. through 2007. The only exception may be Africa, where slight pressure on crop prices occurs over the period (not shown).

[6] The results, reported in Table 9, depict changes in real, not nominal, prices. All prices in the model are relative to the price of a global savings commodity, chosen as the numeraire in our model.

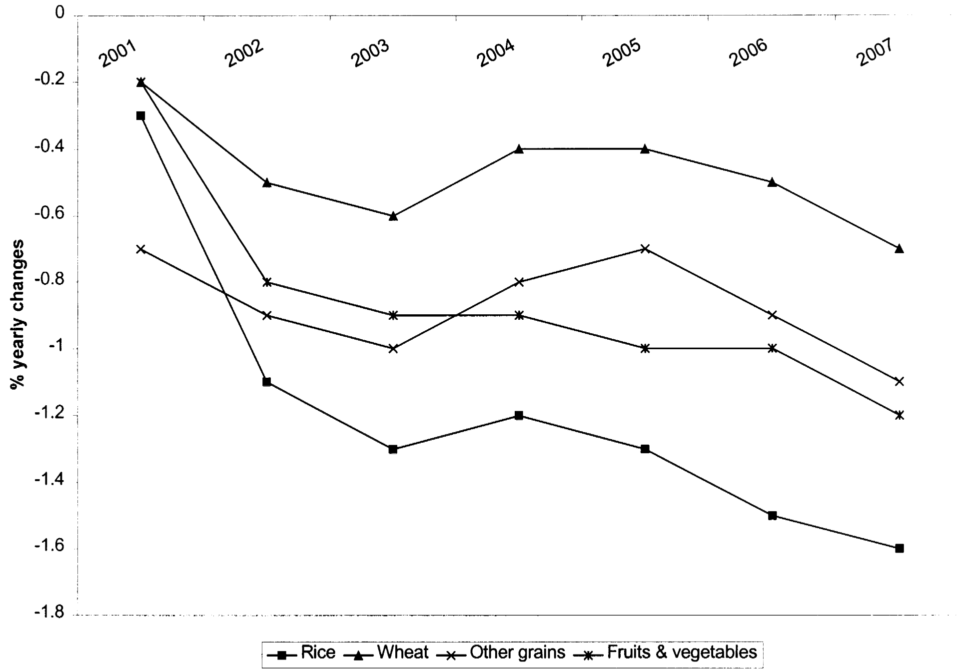

Fig. 1. Yearly growth rates in world prices (source: Simulations with GTAP).

Table 10
Quantity of land services demanded by type of activity in the baseline: average yearly percentage changes[a]

			Forested land					
Region	Cropland	Pastures	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
ANZ	−0.42	0.24	0.18	0.11	0.40	0.58	0.54	0.11
CAN	−0.13	−0.15	−0.02	0.15	0.43	1.02	N/A	N/A
USA	0.02	−0.25	0.15	0.10	0.40	0.81	0.76	0.76
JPN	−0.32	−0.70	N/A	N/A	0.78	0.47	0.81	0.49
OEA	−0.24	0.30	0.30	0.50	1.32	1.60	1.49	1.20
SEA	−0.15	−0.04	N/A	N/A	1.38	1.18	1.44	1.31
EU	−0.31	−0.63	0.08	0.40	0.73	0.87	0.80	0.61
FSU	−0.10	0.20	−0.10	0.04	0.08	0.07	0.20	N/A
OEU	−0.46	0.22	0.01	0.31	1.14	1.18	1.03	0.80
OAS	−0.08	0.04	0.56	0.54	1.29	1.30	2.22	1.35
LAM	−0.22	0.13	0.76	0.90	2.04	2.24	1.12	2.26
AFR	−0.04	0.09	0.53	0.47	0.83	0.82	1.07	1.26

[a] Source: simulations with D-FARM.

The slight rise in the price of world forestry products, however, indicates that pressure on the world's forest resources will continue under our baseline projections. Other evidence supports this as well. Although forestland is projected to increase across all land classes except in the northernmost forests in Canada and the Former Soviet Union (Table 10), timber harvest rates increase as well (Table 11).[7] Hence, economic depletion of forests intensifies in our baseline scenario. These results are consistent with those obtained in a FARM-based study of the impacts of population growth on forests in moist tropical areas of Asia, Africa, and Latin America (Darwin et al., 1996). In our current baseline scenario, however, forest depletion cannot be attributed to the conversion of forestland to agricultural land because cropland and pasture generally decline (Table 10).

To test the importance of technological progress in agriculture we project a less optimistic agricultural TFP growth scenario. Specifically, we assume that after the year 2000, in all regions agricultural TFP growth slows down so that there is no difference between TFP growth rates in agriculture and in the rest of the economy. We implement this by eliminating 0.7 percentage points from the growth in the agricultural TFP parameter in all regions. The comparison between the baseline and this policy simulation reveals possible effects of a slowdown in agricultural research.

4. Effects of a slowdown in agricultural TFP

Lower TFP in the agricultural sector relative to the baseline implies higher agricultural and processed food commodity prices. World farm commodity prices rise by about 0.9% per annum on average relative to baseline in the absence of faster TFP growth in agriculture after 2000 (Table 9). The increase in world commodity prices is driven by the decline in world production of farm and food commodities relative to the baseline (Table 9).

In order to see how these results compare to recent findings in the literature we look at the results produced by Evenson et al. (1999) who focus on agricultural research and productivity in India's rice sector. These authors found that without the technological progress which led to the development of high yielding varieties of rice over the past 40 years, prices of rice in India would likely be as much as 40% higher than they are today. Our study also suggests that, if the growth in agricultural productivity falls to the rate of technological growth in the rest of the economy, in 35–40 years the price of rice in Other Asia, a region in our study dominated by the economy of India, may be 40–47% (or 0.97% per annum on average) higher than the baseline. In addition, we report in Table 12 changes in commodity prices expected in 40 years for all other regions. These results suggest that in the case of a slowdown in agricultural productivity South East Asia might face the largest increases in the prices of most crops relative to the baseline. In almost all cases the prices of farm products in this region are expected to be 50% higher at the end of 40 years compared to the baseline.

Besides higher commodity prices, all regions may need to convert more forestland into farmland as agricultural productivity slows down over the period 2000–2007 and the farm sectors utilize more irrigation water and land compared to the baseline (Tables 13 and 14). For instance, the quantity of farmland demanded in all regions is expected to increase relative to the baseline (Table 14), driving up the regional prices or rents of farmland (Table 14). Given that about 75% of farmland is cropland, the TFP slowdown means higher prices of cropland compared to pastureland relative to the baseline

Table 11
Annual changes in timber harvest rates as a result of economic and population growth in baseline (%)[a]

	Timber harvest rate on land types					
	1	2	3	4	5	6
ANZ	2.59	2.76	2.72	2.74	2.63	2.71
CAN	1.70	1.64	1.64	1.53	N/A	N/A
USA	2.19	2.27	2.06	2.22	2.15	2.13
JPN	N/A	N/A	0.62	0.89	1.01	0.88
OEA	5.83	5.95	5.37	5.19	5.24	5.34
SEA	N/A	N/A	3.48	3.39	3.56	3.51
EU	2.52	2.36	2.19	2.22	2.38	2.30
FSU	2.31	2.23	2.19	2.21	2.17	N/A
OEU	3.20	2.93	2.65	2.55	2.68	2.61
OAS	2.89	3.05	2.86	2.62	3.08	2.77
LAM	2.33	2.41	1.39	1.50	2.40	1.42
AFR	2.94	3.08	2.69	2.57	2.64	2.70

[a] Source: simulations with D-FARM.

[7] Percentage changes in timber harvest rates are estimated by subtracting percent changes in forestland from percent changes in forest output.

Table 12
Projected cumulative changes in commodity prices due to slowdown in agricultural TFP growth over a 40-year period relative to baseline (%)[a]

	PDR	WHT	GRO	V-F	OSD	C-B	PFB	OCR	LIV
ANZ	20.4	36.5	38.8	39.5	41.0	41.0	39.5	38.8	32.9
CAN	44.1	39.5	45.6	40.3	43.3	44.1	41.0	44.1	28.6
USA	48.8	39.5	45.6	43.3	44.9	46.4	39.5	44.9	25.1
JPN	46.4	38.8	39.5	38.0	42.5	42.5	43.3	41.8	14.5
OEA	39.5	35.8	40.3	40.3	41.8	42.5	38.0	44.9	32.9
SEA	53.6	45.6	52.0	56.1	50.4	48.8	59.4	50.4	35.8
EU	37.3	31.4	33.6	27.2	35.1	32.2	35.1	35.1	19.7
FSU	39.5	40.3	43.3	36.5	41.0	43.3	40.3	38.8	17.7
OEU	13.9	31.4	30.7	25.1	35.1	32.9	34.3	34.3	21.1
OAS	47.2	44.1	42.5	40.3	44.9	44.1	43.3	44.9	37.3
LAM	42.5	41.0	41.0	39.5	41.0	40.3	42.5	41.0	51.2
AFR	47.2	45.6	48.0	43.3	48.8	46.4	44.9	45.6	34.3

[a] Source: simulations with D-FARM.

Table 13
Cumulative percentage changes relative to baseline in the price of water and quantity of forestland demanded by land type, 2007[a]

Region	Price of water	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
ANZ	3.4	0.1	0.0	−4.0	−4.7	−3.9	−2.7
CAN	0.3	0.1	−0.8	−2.3	−3.9	N/A	N/A
USA	5.0	0.1	−0.9	−2.5	−3.8	−2.8	−2.7
JPN	2.9	N/A	N/A	−1.6	−1.3	−2.2	−1.3
OEA	13.0	−0.2	−0.8	−2.5	−2.7	−2.5	−2.1
SEA	4.3	N/A	N/A	−2.0	−1.7	−1.8	−1.7
EU	3.9	−0.5	−1.1	−2.4	−2.8	−3.3	−2.7
FSU	7.3	−0.5	−1.3	−3.1	−3.9	−4.1	N/A
OEU	4.3	0.0	−6.7	−2.8	−3.0	−2.6	−2.2
OAS	13.7	−0.1	−0.7	−3.0	−2.6	−4.0	−2.4
LAM	7.2	−0.8	−1.2	−2.9	−2.8	−2.8	−3.0
AFR	11.7	−0.4	−0.9	−2.7	−2.4	−2.7	−2.8

[a] Source: simulations with D-FARM.

due to stronger demand for cropland services as shown in Table 14.

The increased demand for farmland and its accompanying increase in land rents leads to higher farmland income in all regions relative to the baseline (Table 15). Farm income also increases in the alternative case relative to the baseline (Table 15). However, the increases in farm income are expected to be less than half of the increases in farmland income. This suggests that in all regions any benefits from the slowdown will accrue mostly to landowners, not farm workers. Indeed, in poorer regions such as Africa and Other Asia, income and wages of unskilled workers in these economies decline relative to the baseline (Table 15). The loss of productivity in agriculture leads to welfare losses in all regions (Table 15). Most negatively affected are regions with high population growth rates, in which agriculture represents a high proportion of total GDP, such as Africa and Other Asia where in 1995 crops and livestock accounted for 11.9% and 10.8% of GDP, respectively.

Our results also show that the environmental impacts of a slowdown in agricultural TFP are negative. The quantity of forestland demanded declines across most land classes and regions (Table 13). This supports the hypothesis that growth in agricultural TFP helps to prevent the permanent conversion of forestland to other uses. In addition, timber harvest rates increase across all land classes (Table 16). This indicates that growth in agricultural TFP helps to reduce environmental or ecological damages that forestry production generates on land remaining in forests. Thus, slower global growth of agricultural TFP would likely have adverse environmental effects because it is associated both with reductions in forestland and increases in environmental or ecological damages on remaining forestland.

5. Conclusions

This paper is unique in that it analyzes the global effects of economic and population growth and the impact of a slowdown in agricultural TFP growth on agricultural and forest resources using

Table 14
Cumulative percentage changes in land prices and usage relative to baseline, 2007[a]

Region	Farmland		Cropland		Grazeland	
	Price	Quantity	Price	Quantity	Price	Quantity
ANZ	17.4	0.2	23.8	0.6	13.7	0.0
CAN	22.3	0.7	22.6	0.8	20.6	0.5
USA	24.1	0.7	24.8	0.7	21.2	0.9
JPN	15.1	1.6	15.1	1.6	15.7	1.8
OEA	13.5	0.2	15.7	0.3	8.5	0.2
SEA	10.2	0.2	10.0	0.2	12.5	1.2
EU	24.7	1.4	25.0	1.5	23.6	1.1
FSU	24.2	0.3	25.0	0.2	20.8	0.7
OEU	20.6	0.6	21.6	0.9	19.1	0.0
OAS	15.6	0.2	17.1	0.3	11.1	0.0
LAM	17.8	0.2	18.3	0.2	17.0	0.2
AFR	14.4	0.2	15.6	0.2	10.5	0.1

[a] Source: simulations with D-FARM.

Table 15
Cumulative percentage changes in income, wages, and welfare relative to baseline, 2007[a]

Region	Farmland income (2)	Farm income (3)	Income (4)	Wages[b] (5)	Change in welfare (%) (6)	Aggregate welfare effect ($US millions) (7)
ANZ	17.7	8.3	0.1	0.3	−0.1	−351
CAN	23.2	10.2	−0.1	0.1	−0.2	−1279
USA	25.0	13.0	0.3	0.3	0.0	2882
JPN	17.0	8.0	0.0	0.0	−0.1	−5764
OEA	13.8	6.3	0.1	0.3	−0.5	−9510
SEA	10.5	5.6	0.1	−0.3	−0.7	−3995
EU	26.4	9.7	0.1	0.3	−0.1	−4236
FSU	24.6	11.1	−0.3	0.1	−0.3	−1386
OEU	21.3	7.6	−0.1	0.1	−0.3	−3279
OAS	15.9	7.0	−0.9	−0.5	−1.2	−18579
LAM	18.0	7.3	−0.4	−0.4	−0.6	−9991
AFR	14.5	6.5	−0.5	−0.7	−1.3	−7118

[a] Source: simulations with D-FARM.
[b] Wages of unskilled labor.

Table 16
Cumulative percentage changes in timber harvest rates as a result of a slowdown in agricultural TFP relative to baseline, 2007[a]

	Timber harvest rate on land types					
	1	2	3	4	5	6
ANZ	1.2	1.3	1.8	1.5	2.3	2.7
CAN	0.7	1.7	1.7	2	N/A	N/A
USA	1.4	1.9	3.1	1.9	2.1	2.2
JPN	N/A	N/A	1.8	1.4	1.2	1.4
OEA	0.4	0.5	1.6	1.8	1.7	1.5
SEA	N/A	N/A	1.3	1.4	1	1.1
EU	1.5	1.9	2.6	2.5	2.2	2.5
FSU	1.5	1.4	2.6	2.2	2.3	N/A
OEU	0.5	6.5	2	2.3	2	2.2
OAS	0.8	1.1	2	2.1	1.3	1.7
LAM	0.7	0.6	2.3	1.9	2.1	2.1
AFR	0.6	0.6	2	2.2	1.8	1.5

[a] Source: simulations with D-FARM.

a global, dynamic computable general equilibrium model enhanced with natural resource detail (D-FARM). The modeling framework captures growth effects, productivity differences in land resources across regions, the split between skilled and unskilled labor, and the presence of sector-specific factor inputs.

Given the current consensus about the growth of the world economy, we find that the world is not likely to face food shortages and that agricultural activities are likely to present little threat to forest areas over the next decade. In support of Evenson et al.'s findings, our results suggest that prices of agricultural commodities may rise and that forestland may be converted to farmland in the event that growth in agricultural productivity falls to the rate of technological growth in the rest of the economy compared to the baseline. We expect the largest increases in agricultural crop prices to occur in South East Asia. Such losses in agricultural productivity would lead to welfare losses in all regions, with the bulk of the problems faced by regions in which agriculture still accounts for a higher share of the gross domestic product. Slower agricultural TFP growth could have negative environmental effects because it is associated both with reductions in forestland and increases in environmental or ecological damages on remaining forestlands.

Acknowledgements

We thank an anonymous reviewer, Philip Gaut, Thomas W. Hertel, Amyaz Moledina, Vernon Ruttan, and John P. Sullivan for their helpful comments on previous drafts, and Robert McDougall and Terrie Walmsley for providing us with some of the data for this study. This work was funded through a cooperative research agreement between the Economic Research Service of US Department of Agriculture and the Department of Agricultural Economics, Kansas State University. The views expressed in this paper do not necessarily reflect those of the World Bank or the U.S. Department of Agriculture.

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